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APPLICATION OF REMOTE SENSING TECHNIQUES IN LAND-USE PLANNING: FLOOD-PLAIN DELINEATION

by

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Sioux Falls, SD 57198

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FOREWORD

This Bulletin is published in furtherance of the purposes of NASA grant NGL 03-002-313 entitled "Application of Remote Sensing to State and Local Government." The purpose of the grant is to assist, with the use of NASA high-altitude photography and satellite imagery, state and local agencies whose responsibility lies in planning, zoning, and environmental monitoring and/or assessment.

This report is the sixth in a series of publications designed to present information bearing on remote sensing application in Arizona. This study details the Cochise County Planning Department's efforts to delineate areas subject to inundation by storm runoff in a predominantly rural, but rapidly urbanizing semi-arid area. The project was funded jointly by the NASA grant and the Cochise County Planning Department.

INTRODUCTION

Population pressures upon the land resources of Arizona have resulted in the sale and development of areas subject to inundation by floodwaters. These problems are magnified in the predominantly rural areas of Arizona where the availability of relatively low-priced agricultural land and the inadequacy of land-use controls allow various land speculation schemes and unplanned subdivision growth.

Project Concept

In response to the problem of floodplain development, the Arizona legislature passed House Bill 2010 on 3 May 1973. This bill directed local government agencies to outline 100-year floodplains in areas of ongoing land development and to construct a set of ordinances for land-use management in these areas. House Bill 2010, and its supporting documentation from the Arizona Water Commission, outlined a set of general procedures for the delineation of floodprone areas, but was difficult to implement at the county level because of limited financial and personnel resources and a nine-month time-frame for initial compliance.

This report describes the floodplain delineation project conducted by the Planning Department of Cochise County, Arizona, using NASA acquired data. Imagery from Earth Resources Technology Satellite (ERTS-1) and high-altitude aircraft was employed in the project.

If a planning staff is to manage land use within a county-sized jurisdiction of over 4 million acres, it must have access to a data base which can be updated to monitor changes in land use, and which presents data in a form which requires a minimum of interpretive time after analytic

techniques have been developed. The output of the ERTS-1 program met these specifications for the formulation of the data base for local planning efforts. This remotely-sensed data was effectively used with existing available county maps, such as the soil survey, geological and topographic maps, and natural resource and land-use maps available from state and federal agencies.

The Cochise County Planning Department initiated the floodplain delineation project in June 1973. It is the intent of this report to demonstrate that a project such as that stimulated by House Bill 2010 can be conducted in-house by a local planning agency within the constraints of available funds and personnel with the use of remote sensing data. A county planning staff can, with data acquired by aerial sensors, and equipment support from university research facilities, meet much of the data requirement for rational planning decisions.

Equipment and Methods

Table 1 lists the equipment used in the conduct of this project.

Table 1

Cochise County Planning Department, Bisbee

1. Light table
2. Kail K-10 mirror stereoscope
3. Overhead projector and screen
4. 3x and 6x magnifiers

Office of Arid Lands Studies, University of Arizona

1. 1^2S color additive viewer
2. Light table with variable intensity capability
3. Spatial data density slicer

The nine-month time-frame determined by the legislature necessitated the selection of "critical need" areas within the county. Two parameters were analyzed to select areas for floodplain delineation study: first, areas of imminent or ongoing development; and second, portion of the county known to be subject to inundation by storm runoff. The intersect between "development areas" and "flood areas" formed a basis upon which study areas were selected. Several reconnaissance trips and consultation with planning and engineering staff resulted in selection of the following areas: (1) Willcox; (2) Turkey Creek; (3) Douglas; and (4) Sierra Vista-Fort Huachuca (see Figure 1). "Area" in this context is defined as the two adjoining 15 minutes U.S. Geological Survey topographic quadrangles containing the above named locations and significant portions of the watersheds which contribute runoff into these locations.

Parameters of the analysis procedure were soils and geomorphology, vegetation, hydrologic calculations, and historic data. Reckendorf (1968) has reported that this "combination method" is an effective means of delineating areas subject to periodic flooding.

It was found upon attempting to assemble basic data on watershed characteristics and streamflow that little were available; and available data from various sources were not in agreement regarding boundaries. As an example, watershed configuration maps from various sources contained a combination of actual watershed boundaries and administratively-determined boundaries which made the product unusable for generating areas of the necessary scale.

Analysis of watershed configurations and drainage patterns was conducted using a step-down procedure from preliminary, synoptic views on ERTS imagery at a scale of 1:1,000,000, 1:500,000, and 1:250,000, to color infrared

Figure 1. Cochise County, Arizona, Showing Four Study Areas on ERTS-1 Multispectral Scanner Band 7, 1 inch equals 16 miles.

photographs at 1:125,000. Drainage pattern analysis, utilizing remote sensing, is a function of soil color, texture and resulting reflectance and vegetation. All interpretations were ground-checked to confirm accuracy of location of patterns. Ground-checks became fewer as interpretive confidence was developed. Table 2 provides a listing of the ERTS data utilized.

Table 2

ERTS-1 imagery used in project:

Image ID	Date
E 1101-17215-4/5/7	01 Nov 72
E 1101-17221-4/5/7	01 Nov 72
E 1102-17274-4/5/7	02 Nov 72
E 1102-17280-4/5/7	02 Nov 72

Product of ERTS-1 Multispectral Scanner (MSS):

MSS Band	Spectral Range (micrometers)
4	5.0 - 6.0 μm
5	6.0 - 7.0 μm
6	7.0 - 8.0 μm
7	8.0 - 1.10 μm

Soils and Geomorphology

A detailed soils map should be of considerable use in floodplain delineation because soils associated with flood areas are characteristically young and development has been minimal. Floodplain soils lack developed B horizons, as compared to older, more mature soils not subject to flooding. A "B horizon" is an area of alluviation of clays and typically blocky structure.

The soils map of Cochise County (SCS, 1971) showed an area of Whitehouse-Forrest-Tubac soil association northeast of Willcox. This association contains developed soils, and no flooding hazard is normally connected with these soils. Field study resulting from this soil's unusually h[illegible] reflectance on ERTS MSS 4, 5, and 6 and color infrared photography were definitely floodprone and had been inundated recently. Examination of soil profiles revealed a shallow (8-15 cm.) overburden of recent alluvium. Further study of the contributing watershed area revealed an extreme over-grazed condition which has caused increased water yield and extensive erosion. This condition could be detected quite clearly as having a high reflectance on the high-altitude color infrared photography.

General soils maps, as a result of the above finding, were used only as guidelines. If a detailed soil survey is available for an area under study, it can add significantly to the accuracy of image interpretation, and fewer ground-checks need be made. Consultation with local Soil Conservation Service staff is strongly urged during the interpretive process.

A problem common to Southwestern semi-arid environments is the lack of consistent channel geometry to control runoff. The mode of flow in areas of less than two to three percent slope is a sheet configuration after the capacity of minor drainage channels has been exceeded. When these flows coalesce, they may form a nearly continuous sheet several hundred meters wide and ten to twenty centimeters deep in areas of relatively flat topography. The scour regions of this type of flow can be seen quite clearly and readily on bands 5 and 7 of the ERTS imagery and on the color infrared photographs. Scours appear as highly reflective areas occurring on the lower slopes of alluvial fans.

Differential reflectance of scour areas occurring in corridors adjacent to channels was interpreted to represent the approximate limits of the "50 year" and the "100 year" flood events. That is, where differential tones were evident along stream channels, the lighter tones were interpreted to represent more recent and lower volume runoff flows than the darker tones which represented less frequent but more severe runoff events covering larger areas. This approach does not allow one to assess the time between or duration of flow events; however, it clearly delineates boundaries of past flood events of various magnitudes.

Sheet-flow drainage becomes a problem when it consequently affects human activities and uses of land. An example of this interaction that is easily detectable on remotely-sensed data is overgrazing, which accelerates runoff and erosion. The effects of this are severe enough on the upslope rangelands in terms of soil loss; however the subdivision of lands in the discharge area of ep' al streams makes necessary careful monitoring of const on as a means for implementation of floodplain land-use management regulations. The necessary monitoring is most efficiently carried out by an ongoing program, gathering data over time.

The ERTS-1 product, in bands MSS 4, 5, and 7, was used to compile a watershed area map of the entire county, and several runoff-contributing areas outside the county's boundaries. This imagery was used in the form of 70 mm. chips for enhancement in the color additive viewer and in all available enlargement modes. By viewing these transparencies in color enhancement and on the light table, a map of apparent watershed configurations was assembled and plotted at 1:62,500. Ground-checks of the watershed delineation map revealed that subtleties of drainage patterns and erosional features interpreted from ERTS

imagery at 1:250,000 was nearly equal to the output of a similar analysis of the high-altitude color infrared transparencies. Color infrared photography as shown in Figure 2 is an ideal backup system for geomorphic interpretation if analysis at the individual subdivision level is desired as a component of the regulation function of a local planning department.

Vegetation

Vegetation data, both interpreted from remote-sensor sources and observed in detail on the ground, was useful for delineation of floodways. The dominant vegetation types for a given area is consistently associated with soils and moisture regime, as well as with climatological factors.

Primary delineations of riparian (Prosopis dominated) vegetation was conducted using ERTS enlargements in bands MSS 4 and 7. High-altitude color infrared photographs were found necessary for detailed delineations in smaller channels (50 feet in width) (Figure 2). Erosion-affected soil tones in areas adjacent to active channels proved beneficial in that the heightened contrast served to enhance resolution of vegetation-type boundaries. Ground-checked interpretation confirmed a close agreement between areas designated flood hazard zones on the basis of vegetation analysis and those generated by hydrologic calculation.

While photointerpretive techniques based on vegetation analysis are highly useful for floodplain mapping in semi-arid situations, ground observation or low-altitude oblique views are important for refinement of data. Assessment of tree condition in and near channels has potential as a data source. Examination of riparian growth by infrared-sensitive photographic method in a low-altitude oblique mode offers the possibility of partial elimination

Figure 2. NASA Color Infrared Photograph of Paul Spur, Arizona Area.

of ground-checks and the capability of coverage of large areas within a relatively short time.

An additional vegetation-related factor which is worthy of inclusion in the analytical process is flood-deposited debris. This means of establishing high-water limits is obviously limited to ground-check observation, unless the debris is of considerable magnitude. This part of the vegetation-based method overlaps to some extent the historic data method at the recent end of the scale.

Hydrologic Calculation

The procedures used in making the hydrologic calculations were basically those of the U.S. Department of Agriculture Soil Conservation Service (SCS), National Engineering Handbook, Section 4 Hydrology. A detailed, step-by-step process is presented in the SCS publication. All graphic and tabular data generated by this method are on file in the Cochise County Planning Department office in Bisbee, Arizona.

Hydrologic calculations were done based on valley cross-sections surveyed at two-to-three mile intervals, and on the parameters included in the SCS discharge equation:

$$Q_p = \frac{484\ AQ}{\frac{D}{2} + .6\ T_c}$$

Where: Q_p = peak discharge in cfs

A = drainage area in mi^2

Q - storm runoff in inches

D = storm duration in hours

T_c = time of concentration in hours

484 is a constant for units used

Values for variables in the previous equation were determined using curves in the SCS Handbook. Data used to enter the curves were determined by analysis of remotely-sensed imagery with ground-check coordination. One of the variables which is of obvious significance is drainage area; as stated previously this data was not available for most of the county. The watershed map, which was one of the early products of this study, provided figures for drainage area. Time of concentration, which is the time required for water falling on the most hydrologically remote portion of a watershed to reach the point of concentration or discharge, was also obtained during the delineation of drainage patterns. Two additional factors which are necessary in order to obtain values for the component variables in the SCS equation are "curve number" and "soil hydrologic group." These values are the product of a complex of relationships between four basic factors: (1) climate, mainly rainfall and temperature; (2) soil, its resistance to erosion and rate of water intake; (3) topography, length and incline of slope; and (4) canopy. Soil hydrologic groups, as defined by the Soil Conservation Service, are based upon the capacity of a soil to transmit water when the soil is in a saturated condition. A high rate of water transmission is associated with low runoff potential.

Soil hydrologic groups and curve numbers were evaluated using ERTS 70 mm. chips in color infrared enhancement, and high-altitude color infrared photographs in stereovision mode at 3x magnification. The bases for this set of interpretations were general slope class, soil reflectance as an erosion indicator, and apparent density and condition of vegetation cover. Estimates of hydrologic groups were found to be in agreement with soil type-hydrologic group placement determined by SCS in most (approximately 85 percent) of the areas observed.

Operator experience with this type of interpretation could raise the accuracy to approach one hundred percent.

Floodplain lines generated by hydrologic techniques were assumed to be correct, and delineations made based upon the various photointerpretive methods were measured against these lines. Although statistical controls were not part of this project, the confidence level with which one could interpret floodways on the remotely-sensed imagery reached approximately ninety percent; i.e., in a one-mile reach of well-defined channel the floodplain area generated from analysis of all imagery covered approximately ninety percent of the area of inundation derived by hydrologic methods. In areas without well-defined channels or in areas under cultivation, remote-sensor techniques far surpassed hydrologic methods in delineating areas known to be subject to flooding.

Historic Data

The historic data input into the system of floodplain delineations is dependent upon two components: (1) location of high-water marks, and (2) obtaining a record of the amount of rainfall which resulted in the given high-water mark. This was the least reliable of the methods in this floodplain delineation scheme. Degree of availability of data constitutes a significant constraint on this method. Precipitation records in the county are inadequate, and streamflow gauge records are virtually non-existent except on the San Pedro River. Photographic evidence obtained from local newspapers, as aerial photos, in low altitude oblique mode, are often taken by journalists to record floods of significant proportions. Ground photos from newspaper sources can be used to determine water levels relative to structures.

Interpretations made from other methods can be field-checked by interview with local residents, and with employees of town government agencies, who often are directly involved during a flooding event.

APPLICATIONS

Local governmental planning agencies have traditionally regulated the design of new subdivisions by adoption of local regulations, which sometimes require (among other considerations) minimum drainage design criteria. With the passage of mandatory floodplain regulations at the state level, local planning agencies are now faced with the comprehensive delineation of floodplains.

The Cochise County Planning Department (CCPD) responded to this mandate by utilizing NASA remotely sensed data to determine areas of potential flooding.

The success of this project is viewed optimistically, in that calculations submitted by developers on the probabilities of their development being flooded have already been shown to be in error. Subdivision layouts in the vicinity of Willcox, Arizona (Figure3) have been significantly altered (Figure 4) during the approval process of their drainage designs upon demonstration by the CCPD using remotely sensed imagery that the area was floodprone and the watershed boundary was many times greater than supposed by the developer's engineer.

The consequence of misinterpretation of flooding potential in the area would result in runoff exceeding the design features of the development. Cochise County, consisting of 4 million acres, is experiencing rapid development. The CCPD can now, with only limited funds and manpower, guide development more wisely away from floodprone areas through the use of remote sensing techniques.

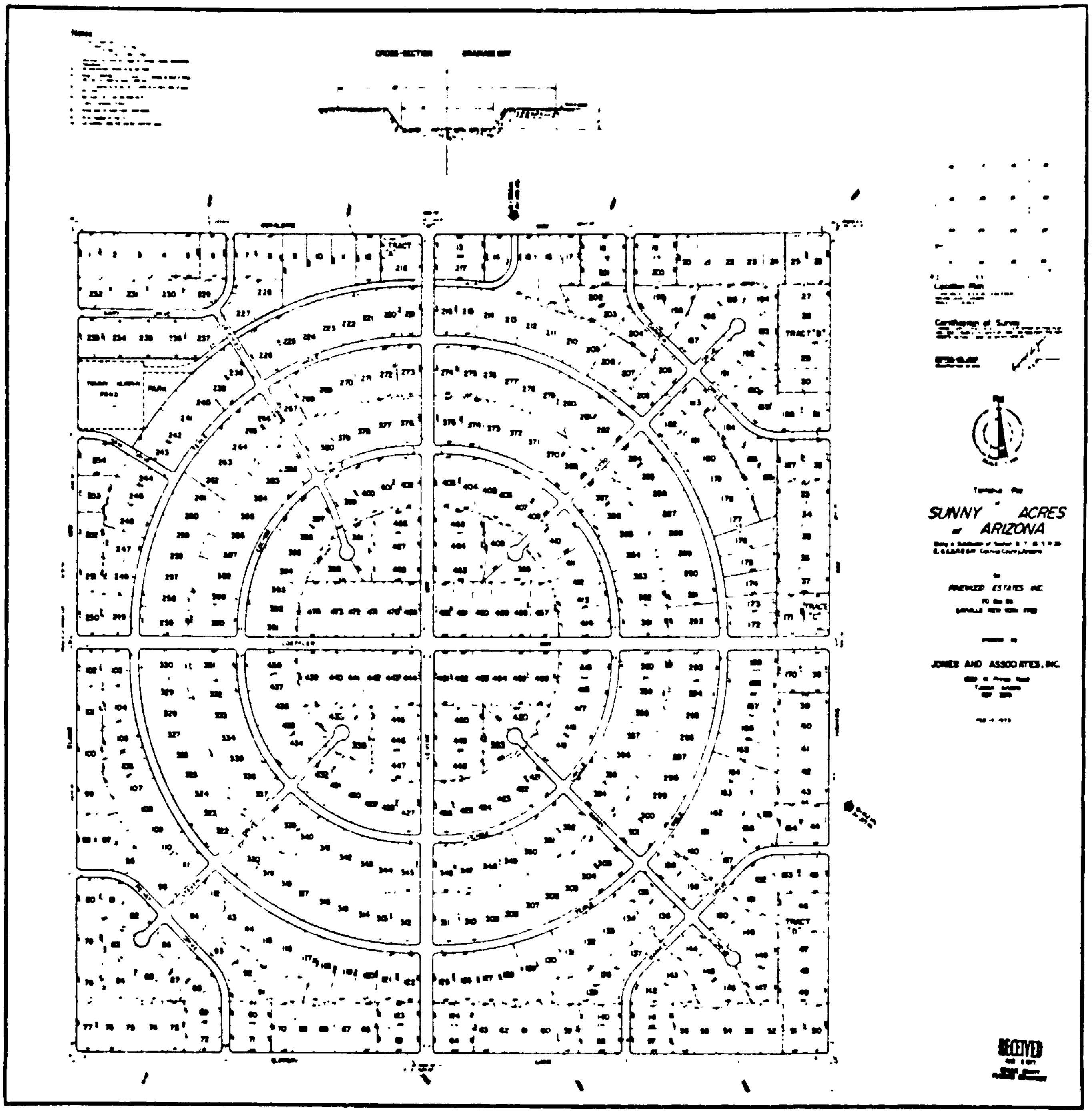

Figure 3. Tentative Plat Sunny Acres, February, 1973

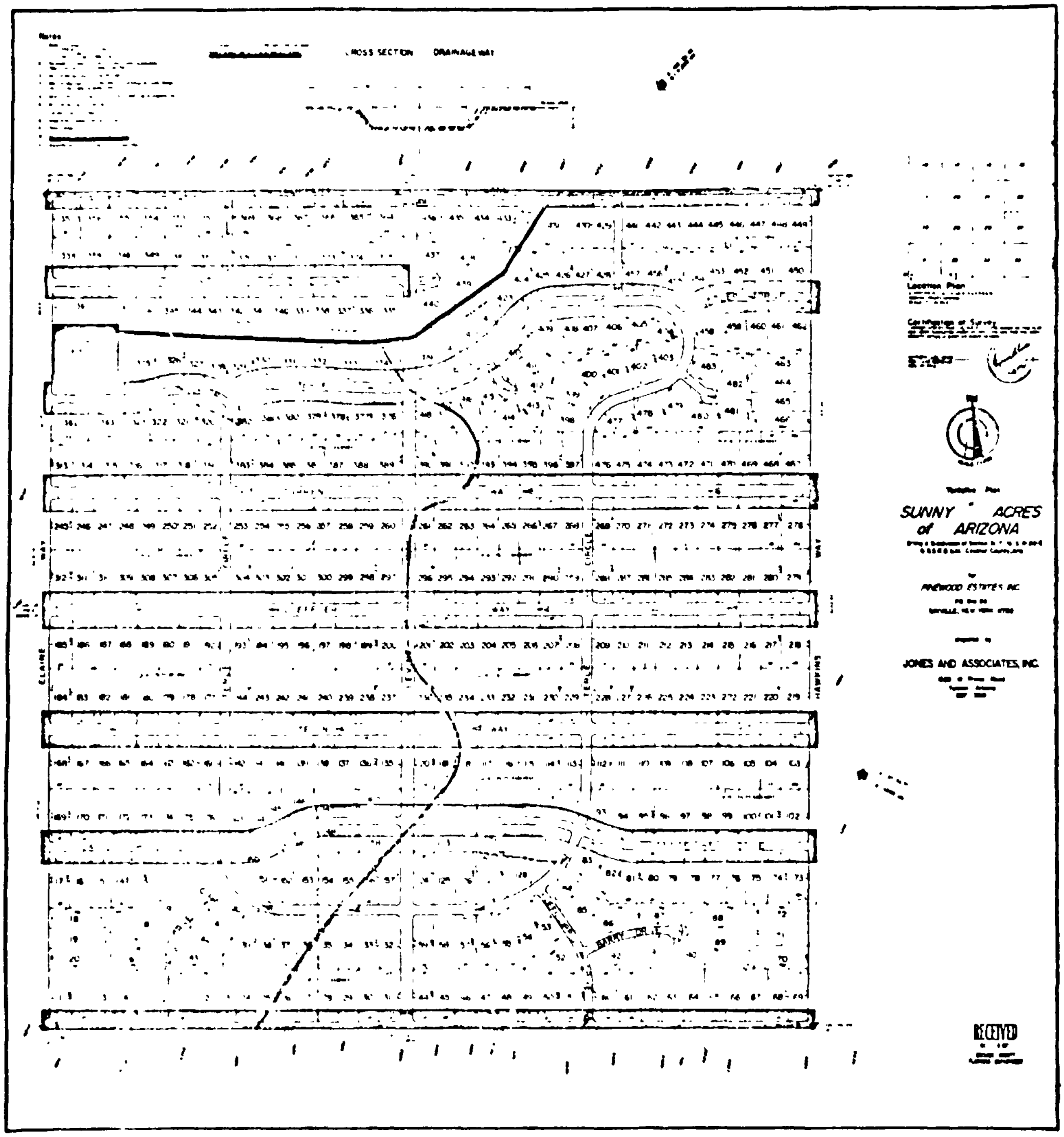

Figure 4. Tentative Plat Sunny Acres, October, 1973

SUMMARY OF SIGNIFICANT RESULTS

The successful application of the ERTS-1 program in a problem area of concern to local planning agencies is a major product of this study. The delineation of areas subject to inundation by means of remotely-sensed data acquisition represents a considerable saving in personnel time. Repeated input from aerial sensor sources provides the planner at the county or town level a potent tool for the formation of a data base and for the monitoring of land-use patterns over time.

The primary output of this project was a set of base map overlays at a scale of 1:62,500 delineating areas which require special regulation, under state law, when proposed for land use involving human habitation or certain classes of storage, as outlined in House Bill 2010 (Figure 5). These overlays were presented to the Board of Supervisors of Cochise County for implementation into their subdivision regulation structure as of 4 February 1974.

A secondary product of the study was county-wide maps (Figure 6) of watershed configurations and of soil hydrologic groups. Further research is anticipated to extend the mapping of watershed areas outside the political boundaries of Cochise County, which will provide data for subsequent rainfall-runoff relationship studies in the area.

All of the data provided from this project will be incorporated into the Cochise County composite computer mapping project now operational under partial funding from the County Supervisors. Land-use planning decisions are only as good as the basic data, and results of this project have improved the pool of information available to the planning staff of Cochise County.

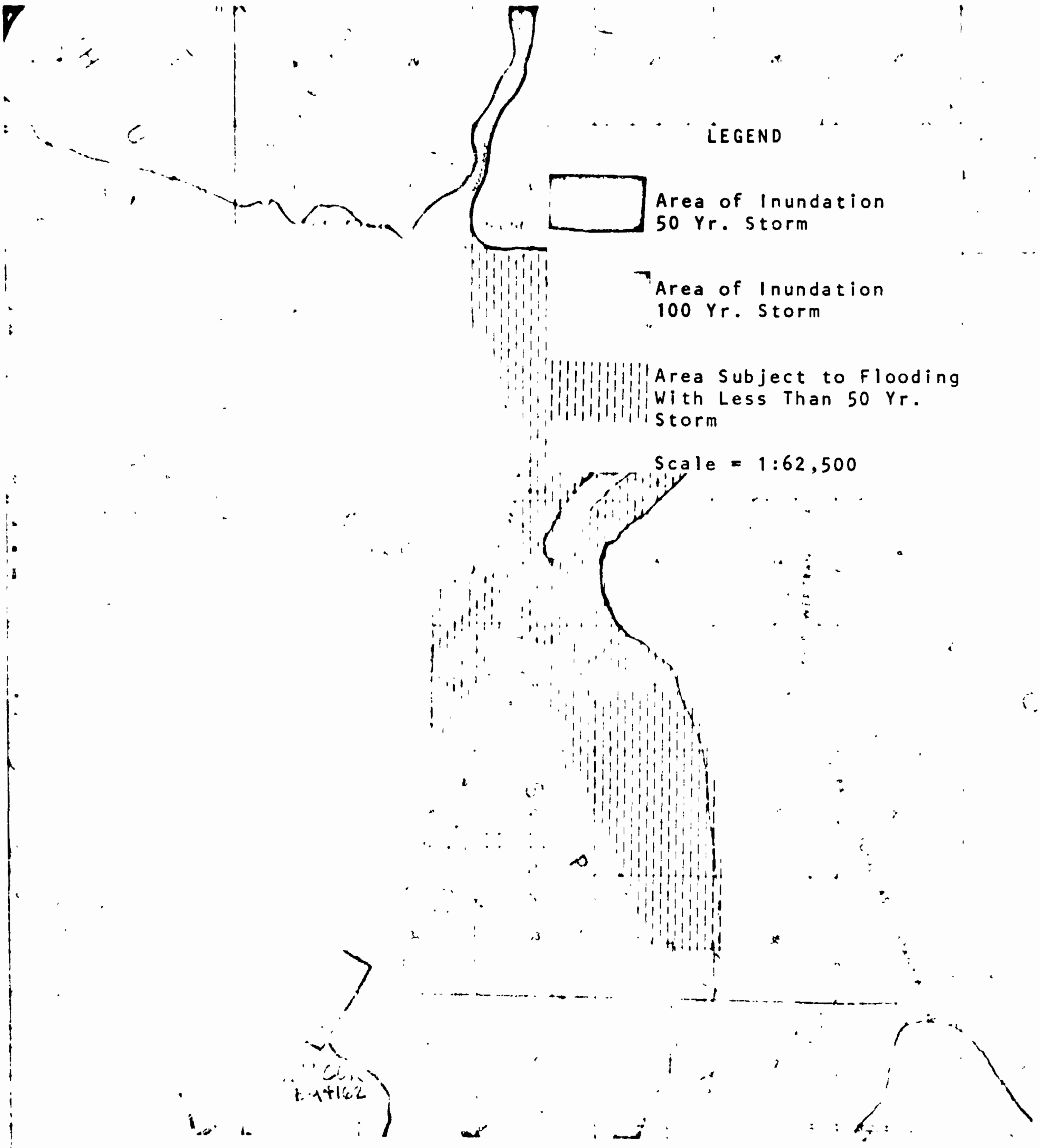

Figure 5. Portion of Remote Sensing Derived Overlay of Flooding Potential (Sheet 2) near Willcox, Arizona

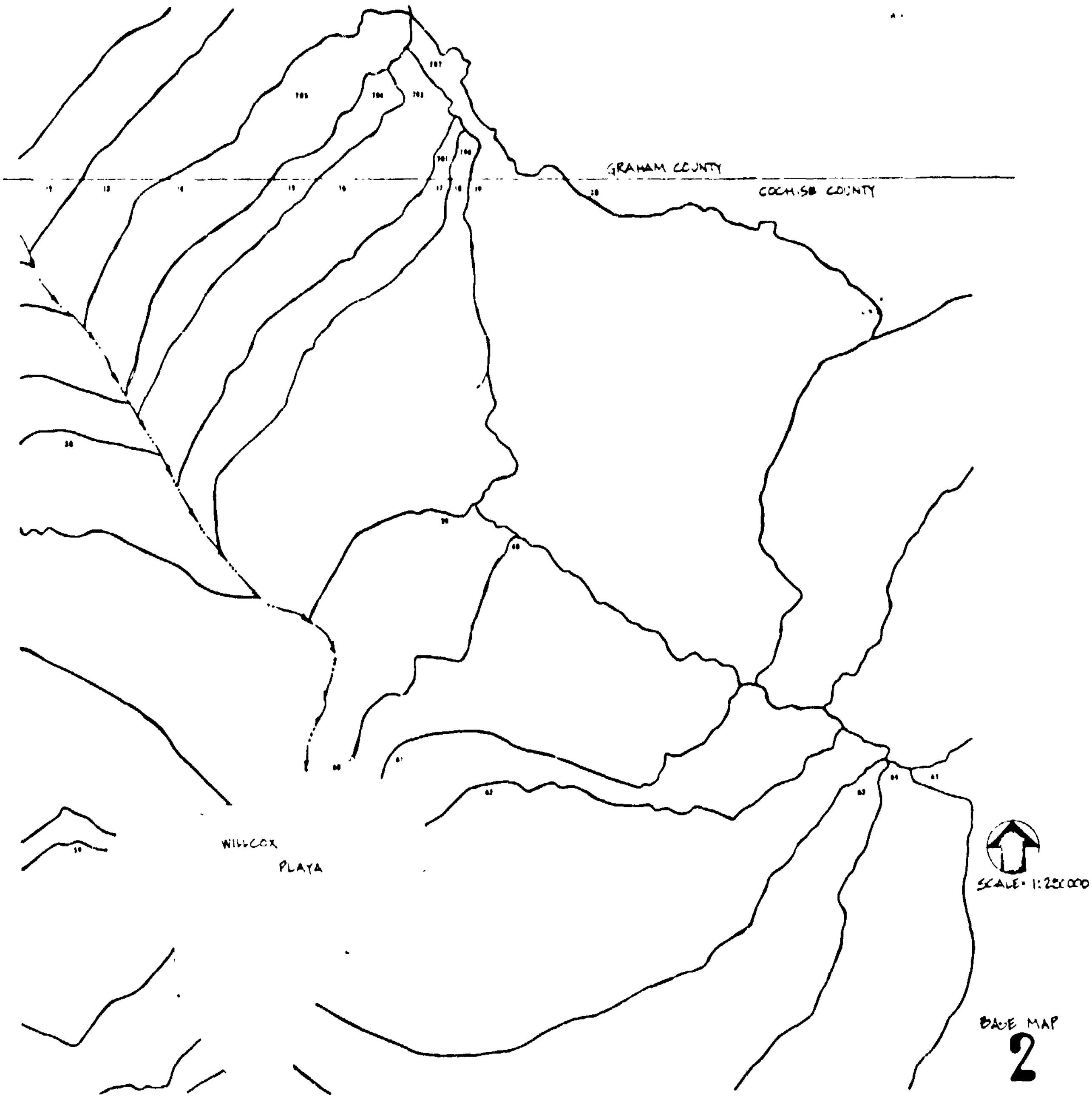

Figure 6. Portion of Delineation of Watersheds Contributing Flow into Willcox Playa Based Upon Interpretation of ERTS-1/MSS Imagery and High-Altitude Color Infrared Photography

REFERENCES

Arizona Water Commission

1973, Floodplain Delineation Criteria and Procedures.

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U. S. Army Corps of Engineers, Los Angeles District

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1971, General Soil Survey, Cochise County, Arizona.

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1971, National Engineering Handbook, Section 4, Hydrology. U.S.G.P.O. Washington, D.C.

U. S. Water Resources Council

1969, Regulation of Flood Hazard Areas to Reduce Flood Losses. U.S.G.P.O. Washington, D.C.

APPENDIX I

COCHISE COUNTY FLOODPLAIN STUDY
ERTS-1 PROPOSAL 100

COSTS

Salaries:

R. Clark	25 man-weeks	3890.00
J. Altenstadter	3 man-weeks	1000.00
F. Ambriz (Draftsman)	2 man-weeks	300.00
		5190.00

Travel:

10,000 miles @ .10/mi	1000.00
Travel to GSFC, Oct. 73	800.00
	1800.00

Photographic Processing:

ERTS Enlargements	300.00
Polaroid Film	25.00
	325.00

Equipment

Kail K-10 Stereoscope	200.00
Polaroid Camera	200.00
	400.00

TOTAL	$7715.00

BENEFITS

Benefits accruing to Cochise County as a result of the application of data acquired by NASA's earth resources technology satellite and accompanying high-altitude aircraft are presented in outline form below:

Watershed Map

A map delineating watershed boundaries and areas for the entire county was generated early in the project, using ERTS-1 multispectral scanner (mss) imagery in enlarged mode (1:250,000), and color infrared photographs (1:120,000). Significant revisior · .. made on existing, partial coverage, drainage maps. This activi   uresented 10 percent of project time.

Soil Hydrologic Group Map

A soil hydrologic group map was compiled, based upon interpretation of potential runoff and infiltration. Several corrections were added to the USDA/Soil Conservation Service hydrologic groups due to environmental changes since initial survey of soil association. The capability of remote sensor techniques to monitor changes in environmental factors, such as overgrazing, removal of vegetation, and erosion and gullying results in a distinct advantage to one who is engaged in land use planning over a large area. This phase occupied 10 percent of project time.

Flood Area Overlays

The final product of the project was a set of overlays, at county base map scale (1:62,500). Delineating areas subject to inundation by storm runoff. The overlays, accompanied by a floodplain management ordinance, are for use by the Cochise County Planning Department and the County Engineer in the process of evaluation of proposed subdivision of land. This phase required 80 percent of project time.

Enhancement of Decision Making Capability

A major problem associated with the management of land use has been acquisition of sufficient data to conduct a rational decision process. A further complication in much of the southwest is the subdivision of lands in remote areas. By employing remote sensor data the county-level planner is supplied with current, synoptic, views of the area of jurisdiction. Data acquired during this project could not otherwise have been obtained within budgetary and personnel constraints.

Cost Savings to Local Government

A project of the areal magnitude required in this instance was early determined to be beyond the reasonable capability of the county engineering staff. The State Legislation which initiated the floodplain study carried no provision for funding, or assistance to local government. By use of imagery received under proposal 100 the County Planning Department was able to comply with the directives of state law, and to avoid the high costs and long lag times associated with Corps of Engineers and consultant-based projects. It is estimated that the cost of this project is at least one order of magnitude below the cost of a traditional, on-the-ground, engineering study.

Benefits to the General Public

Benefits accruing to the general public are an important component of a study concerning land use planning in areas of potential environmental hazard. These benefits, however, are virtually impossible to quantify without a parallel study to assess property values within flood-prone areas. Such a stage vs. damage analysis was not a part of this

project. It is anticipated that savings to the public are considerable when stated in terms of residential development that will not now occur in areas subject to flooding. Real and personal property presently located in flood hazard areas will not, under existing regulations, become a non-conforming use. Such property will be subject to unundation, and may be rebuilt on its site if damaged. The project results will aid those persons whose properties are located in flood-prone areas in obtaining flood insurance under federal programs. Further, all results are open to public examination so that individuals considering purchase of property can evaluate flooding potential of an area of interest.